# APPLICATION FOR U.S. LETTERS PATENT

## TITLE:

## TRILAYERED BEAM MEMS DEVICE AND RELATED METHODS

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This is a divisional application of U.S. Serial No. 10/290,920, filed November 8, 2002.

The present invention relates to the claims in Group II of U.S. Serial No. 09/290,920, drawn to a device, classified in class 200, subclass 181.

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## Description

# TRILAYERED BEAM MEMS DEVICE AND RELATED METHODS

## Cross-Reference to Related Applications

This is a Divisional Application of U.S. Application No. 10/290,920, filed November 8, 2002, which itself claims the benefit of U.S. Provisional Application No. 60/337,527, filed November 9, 2001; U.S. Provisional Application No. 60/337,528, filed November 9, 2001; U.S. Provisional Application No, 60/337,529, filed November 9, 2001; U.S. Provisional Application No. 60/338,055, filed November 9, 2001; US. Provisional Application No. 60/338,069, filed November 9, 2001; U.S. Provisional Application No. 60/338,072, filed November 9, 2001, the disclosures of which are incorporated by reference herein in their entirety. Additionally, the disclosures of the following U.S. Patent Applications filed on November 8, 2002, commonly assigned, are all incorporated by reference herein in their entirety: U.S. Patent Application No. 10/290,779 "MEMS Device Having a Trilayered Beam and Related Methods"; U.S. Patent Application No. 10/291,107 "MEMS Device Having Contact and Standoff Bumps and Related Methods"; U.S. Patent Application No. 10/291,125 "MEMS Device Having Electrothermal Actuation and Release and Method for Fabricating"; and U.S. Patent Application No. 10/290,807 "Electrothermal Self-Latching MEMS Switch and Method."

## Technical Field

The present invention generally relates to micro-electro-mechanical systems (MEMS) devices and methods. More particularly, the present invention relates to a trilayered beam MEMS device and related methods.

## Background Art

An electrostatic MEMS switch is a switch operated by an electrostatic charge and manufactured using micro-electro-mechanical systems (MEMS) techniques. A MEMS switch can control electrical, mechanical, or optical signal flow. MEMS switches have typical application to telecommunications, such as DSL switch matrices and cell phones, Automated Testing Equipment (ATE), and other systems that require low cost switches or low-cost, high-density arrays.

As can be appreciated by persons skilled in the art, many types of MEMS switches and related devices can be fabricated by either bulk or surface micromachining techniques or a combination of both types of techniques. Bulk micromachining generally involves sculpting one or

more sides of a substrate to form desired three-dimensional structures and devices in the same substrate material. The substrate is composed of a material that is readily available in bulk form, and thus ordinarily is silicon or glass. Wet and/or dry etching techniques are employed in association with etch masks and etch stops to form the microstructures. Etching is typically performed on the backside or frontside of the substrate. The etching technique can generally be either isotropic or anisotropic in nature. Isotropic etching is insensitive to the crystal orientation of the planes of the material being etched (e.g., the etching of silicon using a mixture of hydrofluoric, nitric, and acetic acids (HNA) as the etchant). Anisotropic etchants, such as potassium hydroxide (KOH), tetramethyl ammonium hydroxide (TMAH), and ethylenediamine pyrochatechol (EDP), selectively attack different crystallographic orientations at different rates, and thus can be used to define relatively accurate sidewalls in the etch pits being created. Etch masks and etch stops are used to prevent predetermined regions of the substrate from being etched.

On the other hand, surface micromachining generally involves forming three-dimensional structures by depositing a number of different thin films on the top of a silicon wafer, but without sculpting the wafer itself. The films usually serve as either structural or sacrificial layers. Structural layers are frequently composed of polysilicon, silicon nitride, silicon dioxide, silicon carbide, or aluminum. Sacrificial layers are frequently composed of polysilicon, photoresist material, polymide, metals, or various kinds of oxides, such as PSG (phosphosilicate glass) and LTO (low-temperature oxide). Successive deposition, etching, and patterning procedures are carried out to arrive at the desired microstructure. In a typical surface micromachining process, a silicon substrate is coated with an isolation layer, and a sacrificial layer is deposited on the coated substrate. Windows are opened in the sacrificial layer, and a structural layer is then deposited and etched. The sacrificial layer is then selectively etched to form a free-standing, movable microstructure such as a beam or a cantilever out of the structural layer. The microstructure is ordinarily anchored to the silicon substrate, and can be designed to be movable in response to an input from an appropriate actuating mechanism.

Many current MEMS switch designs employ cantilevered beam/plate, or multiply-supported beam/plate geometry for the switching structure. In the case of cantilevered beams/plates, these MEMS switches include a movable, bimaterial beam comprising a structural layer of dielectric material and a layer of metal. Typically, the dielectric material is fixed at one end with respect to the substrate and provides structural support for the beam. The layer of metal is attached on the underside of the dielectric material and forms a movable electrode and a movable contact. The layer

can be part of the anchor or attachment to the substrate. The movable beam is actuated in a direction toward the substrate by the application of a voltage difference across the electrode and another electrode attached to the surface of the substrate. The application of the voltage difference to the two electrodes creates an electrostatic field which pulls the beam towards the substrate. The beam and substrate each have a contact which can be separated by an air gap when no voltage is applied, wherein the switch is in the "open" position. When the voltage difference is applied, the beam is pulled to the substrate and the contacts make an electrical connection, wherein the switch is in the "closed" position.

One of the problems that faces current MEMS switches having a bimaterial beam is curling or other forms of static displacement or deformation of the beam. The static deformation can be caused by a stress mismatch or a stress gradient within the films. At some equilibrium temperature, the mismatch effects can be balanced to achieve a flat bimaterial structure, but this does not correct the temperature effects. The mismatch can be balanced through specific processes (i.e., deposition rates, pressures, methods, etc.), material selection, and geometrical parameters such as thickness. This bimaterial structure of metal and dielectric introduces a large variation in function over temperature, because the metal will typically have a higher thermal expansion rate than the dielectric. Because of the different stales of static stress in the two materials, the switch can be deformed with a high degree of variability. Switch failure can result from deformation of the beam. Switch failure can occur when (1) electrical contact cannot be established between the movable and stationary contacts, (2) electrical contact is established without any actuation, or (3) the operational parameters are driven out of the acceptable specification range due to static deformation or because of the deformation introduced as a function of temperature. A second mode of failure is observed when the movable contact and the stationary contact are prematurely closed, resulting in a "short". Because of the deformation of the beam, the actuation voltage is increased or decreased depending on whether it is curved away from the substrate or towards the substrate, respectively. Because of this variability, the available voltage may not be adequate to achieve the desired contact force and thus contact resistance.

Some current MEMS switch designs having the bimaterial beam attach the metal layer for the movable electrode to the topside of the dielectric material. The metal layer for the moving contact must still be on the underside of the dielectric material. This design can in some instances serve to provide isolation between the movable electrode and the stationary electrode on the substrate; however, this design requires a higher voltage for actuation because the gap distance between the

metal layer and the electrode attached to the surface of the substrate is greater. The effective gap is the sum of the gap between the stationary electrode and the dielectric, and the dielectric thickness. Thus, such a design requires greater power consumption and creates problems with regard to dielectric charging.

A common approach to develop a cross-bar switch array is by a process of forming the cross-bar interconnect structure on a printed wire board (PWB), printed circuit board (PCB), low temperature ceramic composite (LTCC) substrate, or polymer composite substrate and subsequently attaching a switch to the board or substrate. The switch can be attached by a combination of methods such as soldering, wire bonding, bump bonding, flip chip, and other attachment and electric interconnection methods. In this process, the fabrication of the cross-bar interconnect structure is integrated with the MEMS switch process so that they are fabricated on the same substrate with the same process. The advantage of the cross-bar interconnect structure is that an array of input signals can be electrically communicated to a single (or multiple) output of an array of outputs. The array dimensions can be square or rectangular, wherein a square array is an NXN array of N inputs and N outputs and a rectangular array is an NXM array of N inputs and M outputs. The input and output lines of a cross-bar interconnect are electrically connected by the MEMS switch when it is activated in a "closed" position. At each switching node in the cross-bar array, the input/output lines have stationary contact terminals. The integrated MEMS switch functions to establish mechanical and electrical connection between the moving contact and stationary contacts of the input and output lines. The input and output lines communicate through the contact established by the MEMS switch. Alternatively, MEMS switches can be used in a cross-bar array in the usual fashion, if it is attached to the switching nodes of the cross-bar array. This configuration is undesirable because a highly capable fabrication process must be replaced by a less capable assembly process. This will increase the total cost, decrease the quality, complicate the process, and increase the size.

Therefore, it is desirable to provide a fabrication process for producing a structural element (e.g., a beam, plate, and membrane) to improve yield, performance over temperature, actuation, and quality of MEMS switches, it is also desirable to provide a fabrication process for producing a structural element resistant to deformation caused by parasitic or "self actuation. It is also desirable to provide a fabrication process for producing a structural element that is robust to process variations, film stresses, and their gradients. Furthermore, it is desirable to provide a method for forming a cross-bar interconnect and MEMS switch in the same fabrication process. It is desirable to provide a

method that is flexible so that the MEMS switch can be formed and integrated with cross-bar interconnects that are fabricated in another fashion.

## Disclosure of the Invention

According to one embodiment, a method for fabricating a trilayered beam is provided. The method can include depositing a sacrificial layer on a substrate and depositing a first conductive layer on the sacrificial layer. The method can also include forming a first conductive microstructure by removing a portion of the first conductive layer. Furthermore, the method can include depositing a structural layer on the first conductive microstructure, the sacrificial layer, and the substrate and forming a via through the structural layer to the first conductive microstructure. Still furthermore, the method can include the following: depositing a second conductive layer on the structural layer and in the via; forming a second conductive microstructure by removing a portion of the second conductive layer, wherein the second conductive microstructure electrically communicates with the first conductive microstructure through the via; and removing a sufficient amount of the sacrificial layer so as to separate the first conductive microstructure from the substrate, wherein the structural layer is supported by the substrate at a first end and is freely suspended above the substrate at an opposing second end.

According to a second embodiment, a method for fabricating an actuator having a trilayered beam is provided. The method can include forming a first electrode on a substrate and depositing a sacrificial layer on the first electrode and the substrate. The method can also include forming a second electrode on the sacrificial layer and depositing a structural layer on the second electrode, the sacrificial layer, and the substrate. Furthermore, the method can include forming a via through the structural layer to the second electrode; depositing a conductive layer on the structural layer and in the via; and forming a conductive microstructure by removing a portion of the conductive layer, wherein the conductive microstructure electrically communicates with the second electrode through the via. Still furthermore, the method can include removing a sufficient amount of the sacrificial layer so as to separate the second electrode from the substrate, wherein the structural layer is supported by the substrate at a first end and is freely suspended above the substrate at an opposing second end.

According to a third embodiment, a method for fabricating a microscale switch having a trilayered beam is provided. The method can include forming a first electrode on a substrate and forming a first contact on the substrate. The method can also include depositing a sacrificial layer on the first electrode, the first contact, and the substrate. Further, the method can include forming a second electrode on the sacrificial layer and forming a second contact on the sacrificial layer. Additionally, the method can include depositing a structural layer on the second electrode, the second

contact, and the sacrificial layer. The method can include forming a first conductive, interconnect via through the structural layer to the second electrode and forming a second conductive, interconnect via through the structural layer to the second contact. Further, the method can include forming an electrode interconnect on the structural layer that contacts the first interconnect via and forming a contact interconnect on the structural layer that contacts the second interconnect via.

According to a fourth embodiment, a method for fabricating a micro scale switch having a cross-bar interconnect is provided. The method can include the following: forming a conductive interconnection a substrate; depositing dielectric layer on the conductive interconnect; and forming a first conductive, interconnect via through the dielectric layer to the conductive interconnect. The method can also include forming a first contact on the dielectric layer wherein the first contact connects to the first interconnect via and forming a first electrode on the substrate. Additionally, the method can include the following: depositing a sacrificial layer on the first electrode, the first contact, and the substrate; forming a second electrode on the sacrificial layer; forming a first conductive, interconnect via through the structural layer to the second electrode; forming a second conductive, interconnect via through the structural layer to the second contact; and forming an electrode interconnect on the structural layer that contacts the first interconnect via. The method can also include forming a contact interconnect on the structural layer that contacts the second interconnect via.

According to a fifth embodiment, a method for fabricating a microscale switch having a cross-bar interconnect is provided. The method can include the following: forming a conductive interconnect on a substrate; depositing dielectric layer on the conductive interconnect; forming a first conductive, interconnect via through the dielectric layer to the conductive interconnect; and forming a first contact on the dielectric layer wherein the first contact connects to the first interconnect via. The method can also include forming a first electrode on the substrate and depositing a sacrificial layer on the first electrode, the first contact, and the substrate. The method can include the following: forming a second electrode on the sacrificial layer; forming a second contact on the sacrificial layer; depositing a structural layer on the second electrode, the second contact, and the sacrificial layer; forming a second conductive, interconnect via through the structural layer to the second electrode; and forming a third conductive, interconnect via through the structural layer to the second contact. The method can also include forming an electrode interconnect on the structural layer that contacts the second interconnect via and forming a contact interconnect on the structural layer that contacts the third interconnect via.



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According to a sixth embodiment, a method for fabricating a microscale switch having a trilayered beam is provided. The method can include the following: forming a first and second conductive interconnect on a substrate; depositing at least one dielectric layer on the first and second conductive interconnect; and forming a first and second conductive, interconnect via through the at least one dielectric layer to the first and second conductive interconnects, respectively. The method can also include forming a first and second contact on the dielectric layer wherein the first contact connects to the first interconnect via and the second contact connects to the second interconnect via and forming a first electrode on the substrate. Further, the method can include the following: depositing a sacrificial layer on the first electrode, the first contact, and the second contact; forming a second electrode on the sacrificial layer; forming a third and fourth contact on the sacrificial layer; depositing a structural layer on the second electrode, the third contact, the fourth contact, and the sacrificial layer; forming a third conductive, interconnect via through the structural layer to the second electrode; and forming a fourth and fifth conductive, interconnect via through the structural layer to the third and fourth contacts, respectively. The method can also include forming an electrode interconnect on the structural layer that contacts the third interconnect via and forming a contact interconnect on the structural layer that contacts the fourth and fifth interconnect vias..

According to a seventh embodiment a microscale structure is provided. The structure can include a substrate and a structural dielectric arm supported by the substrate and having upper and lower surfaces suspended above the substrate, and having a via registering with the upper and lower surfaces. The structure can also include a first conductive element contacting the lower surface and a second conductive element contacting the upper surface and electrically communicating with the first conductive element through the via.

According to an eighth embodiment, a microscale switch having a conductive interconnect is provided. The switch can include the following: a substrate having a first conductive interconnect and a stationary electrode; a first dielectric layer formed on the first conductive interconnect: and a first stationary contact attached to the first dielectric layer and having electrical communication with the first conductive interconnect. The switch can also include the following: a movable structural layer including a bottom surface suspended over the first stationary contact and a top surface opposing the bottom surface; a movable electrode attached to the bottom surface of the structural layer whereby the movable electrode is separated from the stationary electrode by a first gap; and an electrode interconnect attached to the top surface of the structural layer and connected to the movable electrode for electrical communication. Further, the switch can include a movable contact attached



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to the bottom surface of the structural layer whereby the movable contact is separated from the first stationary contact by a second gap and positioned to contact the first stationary contact when the structural layer moves towards the first stationary contact.

According to a ninth embodiment, a method of implementing switching function in a switch having conductive interconnects is provided. The method can include providing a switch having conductive interconnects. The switch can include a substrate having a first and second conductive interconnect and a stationary electrode and first and second dielectric layers formed on the first and second conductive interconnects, respectively. The switch can also include the following: first and second stationary contacts attached to the first and second dielectric layers, respectively, and having electrical communication with the first and second conductive interconnects, respectively; a movable structural layer including a bottom surface suspended over the first and second stationary contacts and a top surface opposing the bottom surface; and a movable electrode attached to the bottom surface of the structural layer whereby the movable electrode is separated from the stationary electrode by a gap. The method can also include an electrode interconnect attached to the top surface of the structural layer and connected to the movable electrode for electrical communication and a movable contact attached to the bottom surface of the structural layer and positioned to contact the first and second stationary contacts when the structural layer moves towards the first and second stationary contacts. Further, the method can include applying a voltage between the electrode interconnect and the stationary electrode to electrostatically couple the movable electrode with the stationary electrode across the gap, whereby the resilient structural layer is deflected toward the substrate and the movable contact contacts the first and stationary contacts for establishing electrical communication between the first and second conductive interconnects.

Accordingly, it is an object to provide a method for fabricating a MEMS device having a trilayered beam and related methods.

An object having been stated hereinabove, and which is achieved in whole or in part by the trilayered beam MEMS device and related methods described herein, other objects will become evident as the description proceeds when taken in connection with the accompanying drawings as best described herein below.



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## Brief Description of the Drawings

Exemplary embodiments of the invention will now be explained with reference to the accompanying drawings, of which:

Figures 1A - 1V illustrate fabrication steps of a method for fabricating a MEMS switch having a trilayered beam;

Figure 2 illustrates a cross-sectional side view of a MEMS switch having a trilayered beam in a "closed" position: and

Figures 3A - 3K illustrate fabrication steps of another embodiment of a method for fabricating a MEMS switch having a trilayered beam.



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## Detailed Description of the Invention

For purposes of the description herein, it is understood that when a component such as a layer or substrate is referred to as being deposited or formed "on" another component, that component can be directly on the other component or, alternatively, intervening components (for example, one or more buffer or transition layers, interlayers, electrodes or contacts) can also be present. Furthermore, it is understood that the terms "disposed on" and "formed on" are used interchangeably to describe how a given component can be positioned or situated in relation to another component. Therefore, it will be understood that the terms "disposed on" and "formed on" do not introduce any limitations relating to particular methods of material transport, deposition, or fabrication.

Contacts, interconnects, conductive vias, and electrodes of various metals can be formed by sputtering, CVD, or evaporation. If gold, nickel, copper, or PERMALLOY™" ($Ni_xFe_y$) is employed as the metal element, an electroplating process can be carried out to transport the material to a desired surface. The chemical solutions used in the electroplating of various metals are generally known. Some metals, such as gold, might require an appropriate intermediate adhesion layer to prevent peeling. Examples of adhesion material often used include chromium, titanium, or an alloy such as titanium tungsten (TiW). To prevent interstitial or intergranular diffusion, diffusion barriers can be required between different layers. Suitable diffusion barriers include titanium nitride(TiN), molybdenum (Mo), nickel (Ni), tantalum nitride (TaN) or any combination thereof. Alternatively, any other suitable diffusion barrier known to those of skill in the art can be used. For example, nickel can be used as a diffusion barrier to the chromium adhesion layer diffusing along the grain boundaries of a gold metalization.

Conventional lithographic techniques can be employed in accordance with fabrication, such as micromachining, of the invention described herein. Accordingly, basic lithographic process steps such as photoresist application, optical exposure, and the use of developers are not described in detail herein.

Similarly, generally known etching processes can be suitably employed to selectively remove material or regions of material. An imaged photoresist layer is ordinarily used as a masking template. A pattern can be etched directly into the bulk of a substrate, or into a thin film or layer that is then used as a mask for subsequent etching steps.

The type of etching process employed in a particular fabrication step (e.g., wet, dry, isotropic, anisotropic, anisotropic-orientation dependent), the etch rate, and the type of etchant used will

depend on the composition of material to be removed, the composition of any masking or etch-stop layer to be used, and the profile of the etched region to be formed. As examples, poly-etch ($HF:HNO_3:CH_3COOH$) can generally be used for isotropic wet etching. Hydroxides of alkali metals (e.g., KOH), simple ammonium hydroxide ($NH_4OH$), quaternary (tetramethyl) ammonium hydroxide ($(CH_3)_4NOH$, also known commercially as TMAH), and ethylenediamine mixed with pyrochatechol in water (EDP) can be used for anisotropic wet etching to fabricate V-shaped or tapered grooves, trenches or cavities. Silicon nitride can typically be used as the masking material against etching by KOH, and thus can be used in conjunction with the selective etching of silicon. Silicon dioxide is slowly etched by KOH, and thus can be used as a masking layer if the etch time is short. While KOH will etch undoped silicon, heavily doped (p++) silicon can be used as an etch-stop against KOH as well as the other alkaline etchants and EDP. Silicon oxide and silicon nitride can be used as masks against TMAH and EDP. The preferred metal used to form contacts and interconnects in accordance with the invention is gold and its alloys, which are resistant to EDP. The adhesion layer applied in connection with forming a gold component (e.g., chromium) is also resistant to EDP.

Commonly known wet etchants can be used to etch materials such as copper, gold, silicon dioxide, and secondary materials such as the adhesion and barrier materials. For example, gold can be etched with an aqueous solution of $KI_3$ in a temperature range of 20 to 50°C. As another example, chromium (a common adhesive layer) can be wet etched at 25°C is a solution of ceric ammonium nitrate, nitric acid, and $H_2O$. Furthermore, for example, copper can be etched 25°C in a dilute solution of nitric acid. A common method of etching silicon dioxide is with various aqueous solutions of HF or solutions of HF that are buffered with ammonium fluoride.

It will be appreciated that electrochemical etching in hydroxide solution can be performed instead of timed wet etching. For example, if a p-type silicon wafer is used as a substrate, an etch-stop can be created by epitaxially growing an n-type silicon end layer to form a p-n junction diode. A voltage can be applied between the n-type layer and an electrode disposed in the solution to reverse-bias the p-n junction. As a result, the bulk p-type silicon is etched through a mask down to the p-n junction, stopping at the n-type layer. Furthermore, photovoltaic and galvanic etch-stop techniques are also suitable.

Dry etching techniques such as plasma-phase etching and reactive ion etching (RIE) can also be used to remove silicon and its oxides and nitrides, as well as various metals. Deep reactive ion etching (DRIE) can be used to anisotropically etch deep, vertical trenches in bulk layers. Silicon dioxide is typically used as an etch-stop against DRIE, and thus structures containing a buried silicon

dioxide layer, such as silicon-on-insulator (SOI) wafers, can be used according to the methods of the invention as starting substrates for the fabrication of microstructures. For example of a dry etching process, silicon dioxide can be etched in chemistries involving $CF_4$, + $O_2$, $CHF_3$, , $C_2 F_6$, or $C_3 F_8$. As another example, gold can be dry etched with $C_2 Cl_2 F_4$ or $C_4 Cl_2 F_4$ + $O_2$.

An alternate patterning process to etching is lift-off. In the lift-off process, the conventional photolithography techniques are used for creating the negative image of the desired pattern. The lift-off process is typically used to pattern metals which are deposited as a continuous film or films when adhesion layers and diffusion barriers are needed. Additionally, it can be used to pattern other materials. The metal is deposited on the regions for patterning and on top of the photoresist mask (negative image). The photoresist and metal on top are removed to leave behind the desired pattern of metal.

As used herein, the term "conductive" is generally taken to encompass both conducting and semi-conducting materials.

Examples will now be described with reference to the accompanying drawings.

Referring to FIG. 1A-1V a method for fabricating a MEMS switch having a trilayered beam according to a surface micromachining process of the present invention will now be described. The method of fabrication described herein can be used to fabricate other MEMS devices, such as accelerometers, pressure sensors, optical switches, varactors (variable capacitors), variable inductors, and phase shifters. The method of fabrication can be applied to MEMS switches having a trilayered structure, where the trilayered structure can be a doubly-supported beam (attached to the substrate at two ends), a plate/membrane (with edges constrained in different ways, e.g., with four edges constrained), a rigid plate suspended by a multitude of compliant supports such as torsion beams, folded or unfolded beams, and other suspension systems known to those of skill in the art. Referring specifically to FIG. 1A, a starting wafer or substrate **100** is provided, which preferably comprises silicon. Non-limiting examples of materials for use as starting substrate **100** include silicon (in single-crystal, polycrystailine, or amorphous forms), silicon oxinitride, glass, quartz, sapphire, zinc oxide, alumina, silica, or one of the various Group III - V compounds in either binary, ternary or quaternary forms (e.g., GaAs, InP, GaN, AlN, AlGaN, InGaAs, and so on). The conductivity of a silicon layer can be modulated by performing known methods of impurity doping. The various forms of silicon oxides (e.g., $SiO_2$ , other silicon oxides, and silicate glass) can be used as structural, insulating, or etch-stop layers. As known in the art, these oxides can be preferentially etched in

hydrofluoric acid (HF) to form desired profiles. Various methods for adding oxide material to a substrate are known in the art. For example, silicon dioxide can be thermally grown by oxidizing silicon at high temperatures, in either a dry or wet oxidation process. Oxides and glasses, including phosphosilicate glass (PSG), borosilicate glass (BSG), borophoshosilicate glass (BPSG, also termed low-temperature oxide or LTO), as well as silicon-based thin films, can be deposited by chemical vapor deposition (CVD) including atmospheric pressure CVD (APCVD), low-pressure CVD (LPCVD) and low-temperature plasma-enhanced CVD (PECVD), as well as by physical vapor deposition (PVD) such as sputtering, or in some cases by a spin-on process similar to that used to deposit polymers and photoresists. Both stoichiometric and non-stoichiometric silicon nitride can be used as an insulating film, or as a masking layer in conjunction with an alkaline etch solution, and is ordinarily deposited by a suitable CVD method. If the composition of starting substrate **100** is chosen to be a conductive or semi-conductive material, a non-conductive, first dielectric layer **102** is deposited on the top surface of substrate **100**, or at least on portions of the top surface where electrical contacts or conductive regions are desired. Next, a first photolithography mask layer or sacrificial layer **104** is deposited to a uniform thickness for planarizing the top surface of sacrificial layer **104**.

Referring to FIGs. 1B-1C, the process for producing a first conductive microstructure **106** via a lift-off patterning process is illustrated. In this embodiment, first conductive microstructure **106** is a cross-bar interconnect suitable for communication with another electrical device. The conductive microstructure **106** extends into the page to a depth greater than the cross-sectional width. Alternatively, first conductive microstructure **106** can extend into the page a distance equal to or less than its cross-sectional width, in another alternative, first conductive microstructure **106** can represent a ground plate that will extend in all directions to completely underlay the MEMS microstructure. Alternatively, first conductive microstructure **106** can be the fixed plate of a stationary or variable capacitor a part of a planar coil (circular or rectangular) that singularly defines an inductive coil or that is part of a 3-dimensional coil when it is electrically connected to other layers. In yet another embodiment, first conductive microstructure **106** can be any other suitable conductive microstructure for conducting electricity known to those of skill in the art.

Referring specifically to FIG. 1B, first photolithography mask **104** is patterned as shown. A first conductive layer **108** is deposited on first sacrificial layer **104** and the exposed portion of first dielectric layer **102**. First conductive layer 108 comprises gold or any suitable conductive material known to those skilled in the art. Non-limiting examples of depositing first conductive layer **108**

include sputtering, evaporation, electroplating, and any other suitable method known to those skilled in the art. First conductive layer **108** comprises any suitable adhesion material and diffusion barrier material known to those of skill in the art. The adhesion material promotes adhesion of first conductive layer **108** to first dielectric layer **102** and adhesion of any subsequent dielectric layers. The diffusion barrier inhibits the diffusion of first conductive layer **108** into first dielectric layer **102** and into subsequent conductor or dielectric layers.

Next, a lift-off technique is used for removing the remaining first photolithography mask layer 104 and first conductive layer **108** except for the portion forming first conductive microstructure **106**. The lift-off technique comprises immersion in a solvent bath to remove first photolithography mask layer **104** and the unwanted portions of first conductive layer **106**. Thus, referring to FIG. 1C, first conductive microstructure **106** remains formed on substrate **100** to perform the function of electrical interconnection, ground/shielding planes, or heal dissipation. Other non-limiting examples of patterning first conductive microstructure **106** includes etching, milling, electroplating, electroless plating, and any other suitable method known to those skilled in the art.

Referring to FIG. ID, a second dielectric layer **110** is deposited on first dielectric layer 102 and first conductive microstructure **106**. Second dielectric layer **110** is conformal to first dielectric layer **102** and first conductive microstructure **106**. Alternatively, first dielectric layer **102** can be overdeposited and planarized by any suitable method known to those skilled in the art. A planarization technique such as chemical mechanical planarization (CMP) can be implemented after deposition of second dielectric layer **110** to provide a planar surface for subsequent layers. An alternative planarization method is the utilization of a spin-on dielectric that is self-planarizing. As shown in FIG. ID, second dielectric layer **110** is not planarized. If the surface is not planarized, the deposited thickness of second dielectric layer **110** will define the thickness of the interlayer dielectric. If the surface is planarized, the dielectric will be deposited to a thickness greater than the thickness of first conductive layer 108 and second dielectric layer **110**. The CMP process can remove excess material until the surface is planar and the desired interlayer dielectric thickness is achieved.

Referring to FIGs. 1E-1G, a process for forming a recess **112** to place a first conductive via **114** and a second conductive microstructure **116** is illustrated. In this embodiment, second conductive microstructure **116** is a cross-bar interconnect for providing an electrical connection to another electrical device. Alternatively, second conductive microstructure **116** can be any other

suitable conductive microstructure known to those of skill in the art. Referring specifically to FIG. 1E, an etching and patterning process is performed to form recess **112** through second dielectric layer **110** to first conductive microstructure **106**. Referring now to FIG. 1F, a second conductive layer **118** is deposited on first conductive microstructure **106** and in recess **112** to second dielectric layer **110**. Thus, recess **112** is filled with a conductive material to form first conductive via **114**. First conductive via **114** performs the function of electrical interconnection to first conductive microstructure **106**, as described in further detail below. In an alternative embodiment, an electrical interconnection can be made to first conductive microstructure **106** by depositing a plug metal in recess **112**. The plug material can be a material different from that of first conductive microstructure **106** or second conductive layer **118**. Second conductive layer **118** comprises any suitable adhesion material and diffusion barrier material. The adhesion material promotes adhesion of second conductive layer **108** to second dielectric layer **110** and adhesion of any subsequent dielectric layers. The diffusion barrier inhibits the diffusion of second conductor layer **118** into first conductor layer **108**, second dielectric layer **110**, and into subsequent conductor or dielectric layers.

Referring now to FIG. 1G, second conductive microstructure **116** is shown formed from the patterning and etching of second conductive layer **118**. Second conductive microstructure **116** performs electrical interconnection as described in further detail below. Second conductive microstructure **116** can extend into the page to a depth greater than the cross-sectional width of second conductive microstructure **116**. In this embodiment of the cross-bar interconnect, second conductive microstructure **116** will extend perpendicular (to the left and right) to first conductive microstructure **106**. Alternatively, second conductive microstructure **116** can extend into the depth of the page by a distance on the order of the cross-sectional width. In this embodiment, the purpose of second conductive microstructure **116** is only for electrical connection between first conductive layer **108** and second conductive layer **118**. In another application, second conductive microstructure **116** can represent a ground plate that will extend in all directions to completely underlay the MEMS switch. Alternatively, second conductive microstructure **116** can be the fixed plate of a stationary or variable capacitor or part of a planar coil that singularly defines an inductive coil or that is part of a 3-dimensional coil when it is electrically connected to other layers. Furthermore, second conductive microstructure **116** can be any suitable conductive microstructure known to those of skill in the art. The portion of first conductive via **114** extending beyond the surface of second dielectric layer **110** is etched away.

In the process for forming first conductive via **114** and second conductive microstructure **116** described above, second conductive microstructure **116** and first conductive via **114** are formed simultaneously. Alternatively, the material for first conductive via **114** can be deposited independently of second conductive microstructure **116**. The purpose of depositing and patterning first conductive via **114** is to fill first conductive via **114** to the surface of second dielectric layer **110**. Next, second conductive microstructure **116** is deposited and patterned as described above. An alternative process for depositing and patterning first conductive via **114** is by a Damascene process. In a Damascene process, second dielectric layer **110** is planarized as described above. An etching and patterning process is performed to form a recess **112** through second dielectric layer **110** to first conductive microstructure **106** or other patterned microstructure in first conductive layer **108**. The surface of second dielectric layer **110** is planar except for recess **112**. Second conductive layer **118** is deposited on second dielectric layer **110**. Second conductive layer **118** is deposited on first conductive microstructure **106** and in recess **112** to second dielectric layer **110**. Recess **112** is filled with a conductive material to form first conductive via **114**. Second conductive layer **118** can be planarized by any suitable method known to those of skill in the art. A planarization technique such as chemical mechanical planarization (CMP) can be implemented after deposition of second conductive layer **118** to remove all conductive material of second conductive layer **118** except the conductive material that remains to form first conductive via **114**. Second conductive microstructure **116** is patterned and formed as described above.

Referring to FIG. 1H, a third dielectric layer **120** is deposited on second dielectric layer **110**, second conductive microstructure **116**, and first conductive via **114** to produce a conformal surface. Alternatively, the surface of third dielectric layer **120** can be planarized as described above.

Referring to FIGs. 1I-1K, a process for extending first conductive via **114** and forming a second conductive via **122** is illustrated. Referring specifically to FIG. 1I, an etching and patterning process is performed to form recesses **124** and **126**. Recess **124** extends from the top surface of third dielectric layer **120** to second conductive microstructure **116**. Recess **126** extends from the top surface of third dielectric layer **120** to first conductive via **114**. Referring to FIG. 1J, a third conductive layer **128** is deposited on second conductive microstructure **116**, first conductive via **114**, and third dielectric layer **120**. Third conductive layer **128** fills recesses **124** and **126**. Referring now to FIG. 1K, third conductive layer **128** (shown in FIG. 1J) is patterned and etched to form the extension to first conductive via **114** and second conductive via **122** by the methods described above. Second conductive via **122** performs the function of electrical interconnection to second conductive

microstructure **116**. Alternatively, second conductive via **122** and the connection to first conductive via **114** can be formed by the Damascene technique described above or by other suitable methods known to those of skill in the art.

Referring to FIGs. 1L-1M, a process for producing a first stationary contact **130**, a second stationary contact **132**, and a stationary electrode **134** is illustrated. Referring to FIG. 1L, a conductive layer is deposited on first conductive via **114**, second conductive via **122**, and third dielectric layer **120**. The conductive layer is patterned as described above. Referring to FIG. 1M, first stationary contact **130**, second stationary contact **132**, and stationary electrode **134** are formed simultaneously. Alternatively, first stationary contact **130** and second stationary contact **132** can be formed preceding or following the formation of stationary electrode **134**. This sequence of formation will allow first stationary contact **130** and second stationary contact **132** to be formed from different conductive materials, patterned by different patterning methods, or deposited by different deposition methods than stationary electrode **134**. For example, first stationary contact **130** can be formed by evaporation deposition and etching. Alternatively, a via plug, a stud, a post, electrical interconnection, transmission lines, waveguides, stationary actuation electrodes, stationary contact electrodes, electrode interconnects, or any other suitable structure known lo those of skill in the art can be formed. First stationary contact **130**, a second stationary contact **132**, and a stationary electrode **134** are formed simultaneously in this process. Alternatively, components **130**, **132**, and **134** can be formed in separate processes.

First stationary contact **130**, second stationary contact **132**, and stationary electrode **134** comprise a conductive material such as gold or another suitable metal known to those of skill in the art. Alternatively, first stationary contact **130**, second stationary contact **132**, and stationary electrode **134** can comprise a semiconductor such as polysilicon, a conductive polymer, or any other suitable conductive material known to those of skill in the art. If first stationary contact **130** and second stationary contact **132** are made of a different material than stationary electrode **134**, stationary electrode **134** are preferably made of a much lower conductivity. First stationary contact **130** and second stationary contact **132** should be of very high conductivity material such as copper, aluminum, gold, or their alloys or composites.

Referring to FIG. 1N, a first sacrificial layer **136** is deposited to a uniform thickness such that its top surface is preferably planarized. First sacrificial layer **136** defines the gap between components **130**,**132**, and **134** and a trilayered beam structure to be formed thereon, as described in detail below. First sacrificial layer **136** comprises a polymer. Alternatively, first sacrificial layer **136**

can be a metal, semiconductor, dielectric or any other suitable material known to those of skill in the art such that the removal chemistry is compatible with the other electrical and structural materials. Primarily, first sacrificial layer **136** defines the gap between components on substrate **100** and the trilayered beam structure. Alternatively, a conductive material can form electrical interconnects, transmission lines, waveguides, stationary capacitor plates, or stationary inductor elements. Alternatively, a dielectric or polymer sacrificial layer can be used to define an interlayer dielectric to increase capacity between stationary capacitor plates, to increase isolation between stationary electrodes, as a mechanical support or spring element for the trilayered beam structure. In these embodiments, first sacrificial layer **136** is preferably protected by layers of the trilayered beam structure during the release etch described in more detail below.

Referring to FIGs. 1O-1P, a process for producing a movable electrode **138** is illustrated. Referring to FIG. 1O, a fourth conductive layer **140** is deposited on first sacrificial layer **136**. Fourth conductive layer **140** is patterned as described above. Referring to FIG. 1-P, movable electrode **138** is formed. Movable electrode **138** comprises a conductive material such as gold or any other suitable metal. Alternatively, movable electrode **138** can comprise a semiconductor such as polysilicon, a conductive polymer, or any other suitable conductive material known to those skilled in the art. Alternatively, fourth conductive layer **140** can be patterned to form a movable contact electrode, a movable-contact bar, a movable plate of a variable capacitor, a movable inductor of a variable inductor, a section of an air bridge transmission line/waveguide, electrical interconnects, electrode interconnect layers, a structural element of the trilayered beam structure, and as part of the attachment between the structural layer described below, and substrate **100**.

Referring to FIGs. 1Q-1R, a process for producing a structural layer **142** for providing structure for the beam and attaching the beam to substrate **100** is illustrated. Referring specifically to FIG. 1Q, first sacrificial layer **136** is patterned and etched (dry or wet) through to third dielectric layer **120** as shown for forming a structure to attach the beam to substrate **100** and suspend the beam above components **130**, **132**, and **134**. Alternatively, first sacrificial layer **136** can be patterned by other suitable methods known to those of skill in the art such as lift-off, electroplating, electroless plating, or photoexposure and ashing. Primarily, the patterning of first sacrificial layer **136** defines the location of the attachment portion of the trilayered beam structure to substrate **100**. Alternatively, first structural layer **142** is patterned to form insulating interfaces for electrical interconnects, transmission lines, waveguides, stationary capacitor plates, stationary inductor elements, or interlayer dielectrics. Referring to FIG. 1R, structural layer **142** is deposited on third dielectric layer **120**, first

sacrificial layer **136**, and movable electrode **138**. Structural layer **142** preferably comprises silicon dioxide which can be deposited by sputtering, evaporation, spin-on, oxidations, or other suitable methods known to those of skill in the art. Alternatively, structural layer **142** can comprise silicon nitride, silicon oxynitride, aluminum oxide, polymers, or any other suitable non-conductive, resilient material known to those of skill in the art. Structural layer **142** is resilient and provides desired isolation between stationary contacts **130** and **132** and the contacts on the beam as described below. Furthermore, structural layer **142** provides isolation between stationary electrode **134** and the movable electrodes on the beam as described below.

Referring to FIGs. 1S-1U, a process is illustrated for simultaneously producing the following conductive microstructures: a first movable contact **144**, a second movable contact **146**, a first interconnect **148**, a second interconnect **150**, an electrode interconnect **152**, a third interconnect **154**, and an electrical connection **156**. Preferably, the dimensions of movable electrode **138** are 180 x 350 microns. Alternatively, movable electrode **138** can be any other suitable dimensions. These dimensions are determined by desired functionality and manufacturability requirements. Preferably, the dimensions of electrode interconnect **152** are 180 x 350 microns. Referring specifically to FIG. IS, recesses **158**, **160**, and **162** are etched through structural layer **142**. Additionally, a recess **164** is etched into structural layer **142**. Recess **158** is patterned and etched through structural layer **142** and into first sacrificial layer **136** for forming first interconnect **148** and first movable contact **144**. First movable contact **144** and second movable contact **146** comprise a conductive material such as copper, gold, aluminum, their alloys or composites, or any other suitable metal known to those of skill in the art.

Recess **158** is etched into first sacrificial layer **136** so that first movable contact **144** extends beyond structural layer **142**. Recess **160** is patterned and etched through structural layer **142** and into first sacrificial layer **136** for forming second interconnect **150** and second movable contact **146**. Recess **160** is etched into first sacrificial layer **136** so that second movable contact **146** extends beyond structural layer **142**. Recess **162** is patterned and etched through structural layer **142** for forming third interconnect **154** to movable electrode **138**. Recess **164** is patterned and etched through structural layer **142** to form a suspended end of the beam and the unconstrained side of the beam. Recesses **158**, **160**, **162**, and **164** can be etched by a dry or wet etch processor patterned by other suitable methods known to those of skill in the art. The simultaneous fabrication of recesses **158**, **160**, **162**, and **164** provide simplification of the overall process relative to the number of photolithography steps and mask layers. Alternatively, it may prove beneficial to form recesses **160**,

**162**, and **164** through structural layer **142** and into first sacrificial layer **136** to form first interconnect **148** and first movable contact **144**. The formation of recesses **160**, **162**, and **164** through structural layer **142** requires a different process than the formation into first sacrificial layer **136**. Additionally, recess **164** can be formed in another step because it is only required to be formed through structural layer **142** and not first sacrificial layer **136**. Additionally, recess **164** can be formed by patterning and etching structural layer **142** at the free end of the beam and along the sides, but not at the portion of structural layer that attaches to substrate **100**. The sequence of the alternative steps must be determined by simplicity and compatibility. Alternatively, first movable contact **144** and second movable contact **146** can be formed by another pattern in fourth conductive layer **140**. Alternatively, first movable contact **144** and second movable contact **146** can be patterned and formed in first sacrificial layer **136**. Additionally, a pattern in fourth conductive layer **140** can coincide with the pattern for first movable contact **144** and second movable contact **146** as formed in first sacrificial layer **136**. First movable contact **144** and second movable contact **146** can be patterned and formed by methods known to those with skill in the art.

Movable contacts **144** and **146** are required to establish electrical communication between first stationary contact **130** and second stationary contact **132**. The electrical communication is established when first movable contact **144** is in close proximity to first stationary contact **130** and when second movable contact is in close proximity to first stationary contact **130**. The electrical communication is completed through a path that includes first stationary contact **130**, first movable contact **144**, first interconnect **148** (the electrical connection described in further detail below), second interconnect **150** (the electrical connection described in further detail below), and second movable contact **146**. First movable contact **144** and second movable contact **146** are shown in the plane of the cross-section with first movable contact **144** nearest the free end of the beam and second movable contact **146**. In this embodiment, first movable contact **144** establishes contact with first stationary contact **130** and then second movable contact **146** establishes contact with second stationary contact **132**. Alternatively, the primary configuration has first movable contact **144** and second movable contact **146** located at the same position along the length of the beam. In this configuration, first movable contact **144** and second movable contact **146** are separated relative to each other as shown in FIG. 1U. Movable contacts **144** and **146** establish contact with stationary contacts **130** and **132**, respectively.

In another embodiment, there is a single movable contact and stationary contact. In this embodiment, the second movable contact functions as a static contact at the fixed end of the beam.



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The static contact establishes electrical connection through a via in structural layer **142** to second movable contact **146** at the fixed end of the beam. In this embodiment, the electrical connection between second movable contact **146** and the static contact will transverse the length of the beam from the location of second movable contact **146** at the free end of the beam to the static contact at the fixed end of the beam.

Referring to FIG. 1T, a fifth conductive layer **166** is deposited on first sacrificial layer **136** and structural layer **142**. Fifth conductive layer **166** is patterned by a method as described above.

Referring to FIG. 1U, electrode interconnect **152** and electrical connection **156** are formed. Electrode interconnect **152** is a structural match to movable electrode **138**. In one alternative, the geometry and dimensions of electrode interconnect **152** and movable electrode **138** are matched exactly. The exact matching of these structures provide more robustness to film stress and temperature induced deformation of the beam. In another alternative for achieving similar robustness to film stress and temperature induced beam deformation, electrode interconnect **152** and movable electrode **138** are designed to be structurally similar but geometrically and dimensionally different. The structural response of electrode interconnect **152** is designed to be similar to movable electrode **138** to minimize the effects and variations due to the film stresses and temperature independent of the geometry or dimensions matching. As shown, electrical connection **164** connects first movable contact **144** and second movable contact **146** via first interconnect **148** and second interconnect **150**. Electrode interconnect **152** provides an electrical connection to a voltage source (not shown) via electrical connection **164**. Movable electrode **138** is provided an electrical connection to the voltage source via another electrical connection (not shown).

Referring to FIG. 1V, the final step in fabricating the MEMS switch is illustrated. In this step, first sacrificial layer **136** is removed to form a trilayered beam, generally designated **168**. First sacrificial layer **136** can be removed by any suitable method known to those of skill in the art.

The MEMS switch is illustrated in an "open" position wherein a gap exists between first movable contact **144** and first stationary contact **130** and between second movable contact **146** and second stationary contact **132**. In the "open" position, no electrical connection is established between first movable contact **144** and first stationary contact **130** and between second movable contact **146** and second stationary contact **132**. Movement of the MEMS switch to a "closed' position can be effected by application of a voltage across stationary electrode **134** and electrical connection **156** via a voltage source. Voltage source can be electrically connected to stationary

electrode **134** and electrical connection **156** by a suitable method known to those of skill in the art. Movable electrode **138** is energized by the voltage application due to the electrical connection of movable electrode **138** through electrode interconnect **152**, third interconnect **154**, and electrical connection **156**. When the voltage is applied, an equal and opposite charge is generated on stationary electrode **134** and movable electrode **138**. The charge distribution on the opposing electrodes produces an electrostatic force that is balanced by the elastic forces of the now deformed beam. As the voltage is increased, the charge increases in a non-uniform and non-linear fashion across the surface of the beam until an instability point is reached. The stability point is defined by the inability of the elastic forces to maintain equilibrium with the electrostatic forces and the beam snaps through to establish contact. At this point, the voltage can continue to be increased, thereby increasing the contact force and reducing the contact resistance up to the limit of the isolation limits of the beam. The isolation limits are defined by a dielectric breakdown, a gas discharge or breakdown, or an elastic breakdown where the beam snaps through a second time to short the electrodes. Methods known to those skilled in the art can be applied to maximize this isolation. Alternatively, the voltage can be decreased until the release voltage is reached where the beam snaps away from the substrate to "open" the contacts. The release voltage is less, typically, than the pull in voltage that determined closure of the contacts. A monotonic excursion of the voltage-time function is not required to facilitate this operation, such that the switch operates rather instantaneously. The electrical connection **156** and stationary electrode **134** are designed for structural similarity so that the beam is largely flat in the "open" position. Additionally, this structural similarity enhances the performance over temperature because of the thermomechanical balance across the beam.

Referring to FIG. 2, the fabricated MEMS switch is illustrated in a "closed" position wherein first movable contact **144** contacts first stationary contact **130** and second movable contact **146** contacts second stationary contact **132**. Thus, in the "closed" position, an electrical connection is established between first movable contact **144** and first stationary contact **130** and between second movable contact **146** and second stationary contact **132**. Additionally, electrical connection is established between first conductive microstructure **106** and second conductive microstructure **116** by the configuration of components **148**, **150**, and **164**. The MEMS switch is returned to an "open" position when the voltage applied across movable electrode **138** and stationary electrode **134** is reduced sufficiently such that the reflexive force of structural layer **142** returns beam **168** to a natural position.

Referring to FIGs. 3A - 3K, another embodiment of a method for fabricating a MEMS switch having a trilayered beam according to a surface micromachining process of the present invention will now be described. Referring specifically to FIG. 3A, a substrate **300** is provided. Substrate **300** comprises silicon. Alternatively, substrate **300** can comprise any other suitable material known to those of skill in the art. If the composition of substrate **300** is chosen to be a conductive or semi-conductive material, a non-conductive, first dielectric layer **302** is deposited on the top surface of substrate **300**, or at least a portion of the top surface where electrical contacts or conductive regions are desired.

Referring to FIG. 3B - 3C, a process for producing a stationary contact **304** and a stationary electrode **306** is illustrated. Referring to FIG. 3B, a first conductive layer **308** is deposited on first dielectric layer **302**. First conductive layer **308** is patterned as described above. Referring to FIG. 3C, stationary contact **304** and stationary electrode **306** are formed simultaneously. Alternatively, stationary contact **304** and stationary electrode **306** can be formed in separate processes.

Referring to FIG. 3D, a sacrificial layer **310** is deposited to a uniform thickness such that its top surface is preferably planarized. Sacrificial layer **310** defines the gap between stationary contact **304** and stationary electrode **306** and a trilayered beam structure, described in detail below. Sacrificial layer **310** comprises a polymer. Alternatively, sacrificial layer **310** can be a metal, dielectric or any other suitable material known to those of skill in the art such that the removal chemistry is compatible with the other electrical and structural materials.

Alternatively, sacrificial layer **310** can be patterned and etched such that contact bumps are recessed below structures formed on the underside of the beam structure or to form a larger structure that is recessed. Alternatively, recesses can be formed by other suitable means known to those of skill in the art.

Referring to FIGs. 3E - 3F, a process for producing a movable contact **312** and a movable electrode **314** is illustrated. Referring to FIG. 3E, grooves **316**, **318** and **320** are etched in sacrificial layer **310**. Grooves **316** and **318** are etched in sacrificial layer **310** for movable contact **312** and movable electrode **314**, respectively. Groove **320** is formed for forming a structure to attach the beam to substrate **300** and suspend the beam above components **304** and **306**. Referring now to FIG. 3F, a conductive layer is deposited on sacrificial layer **310** until grooves **316** and **318** are filled. Next, the conductive layer is patterned as described above to form movable contact **312** and movable electrode **314**.

Referring to FIG. 3G, a structural layer **322** is deposited on movable contact **312**, movable electrode **314**, sacrificial layer **310**, and first dielectric layer **302**. Structural layer **322** comprises oxide in this embodiment.

Referring to FIG. 3H - 3J, a process for simultaneously producing the following conductive microstructures: a contact interconnect **324**, an electrode interconnect **326**, and interconnect vias **328** and **330**. Referring specifically to FIG. 3H, recesses **332** and **334** are etched into structural layer **322** for forming interconnect vias **328** and **330**, respectively. Recesses **332** and **334** are etched through structural layer **322** to movable contact **312** and movable electrode **314**.

Referring now to FIG. 3I, a second conductive layer **336** is deposited on structural layer **322** and into recesses **332** and **334** as shown for forming an electrical connection from movable contact **312** and movable electrode **314** to the top surface of structural layer **322**. Next, second conductive layer **336** is patterned for forming contact interconnect **324** and electrode interconnect **326** as shown in FIG. 3J. Interconnect vias **328** and **330** can be formed by another conductive layer that would precede the deposition of second conductive layer **336** described above.

Stationary contact **304**, stationary electrode **306**, movable contact **312**, movable electrode **314**, electrode interconnect **326**, contact interconnect **324**, and interconnect vias **328** and **330** comprise a metal in this embodiment. Preferably, movable electrode **314** and electrode interconnect **326** are fabricated of the same material and dimensioned the same in order to perform two functions. First, it provides mechanical balance on both sides of structural layer **322**. The mechanical balance is provided because of the elastic symmetry, because the films are deposited in the same way to produce a symmetric stress field, and because the thermal expansion properties are symmetric. The elastic symmetry is preserved by using the same material and by using the same dimensions. The symmetric stress field is produced by depositing the same materials using the same process and thicknesses. The symmetric thermal expansion properties minimize any variation in the switch operation with respect to temperature because the same material is on either side of structural layer **322**. This means that any functional variation exhibited by the MEMS switch depends primarily on the process variation, which can be minimized by the appropriate optimization of the design in the process. Secondly, it helps the current carrying capacity of the contact. It is preferable that the trilayered beam has the same type metal, deposited by the same process, patterned in the same geometry, and deposited to the same thickness, but the use of different materials could be accommodated with the appropriate design and characterization. To address the issues of contact adhesion, cold welding, or hot welding, stationary contact **304**, stationary electrode **306**, movable

electrode **314**, movable contact **312**, electrode interconnect **326**, contact interconnect **324**, and interconnect vias **328** and **330** could be different materials or different alloys of the same materials. The material selection minimizes contact resistance and failures such as stiction.

Referring to FIG. 3K, the final step in fabricating the MEMS switch is illustrated. In this step, sacrificial layer **310** is removed to form a trilayered beam, generally designated **338**. Sacrificial layer **310** can be removed by any suitable method known to those of skill in the art.

The MEMS switch is illustrated in an "open" position. In a "closed" position, beam **338** is deflected towards substrate **300** and movable contact **312** contacts stationary contact **304**. As described above, a voltage can be applied across electrode interconnect **326** and stationary electrode **306** for moving the MEMS switch into a "closed" position.

It will be understood that various details of the invention may be changed without departing from the scope of the invention. The switch embodiments described above can be applied to cantilever beams, doubly supported beams, plates or other known type switch geometries known to those of skill in the art. Furthermore, the foregoing description is for the purpose of illustration only, and not for the purpose of limitation - the invention being defined by the claims.



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